THEORY TEACHING IN CHEMISTRY.

By RUFUS P. WILLIAMS.

From Rufus P. Williams,
North Cambridge,
Mass.

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It is my belief that every professional person, no matter how humble his station, should endeavor to contribute something to the sum of knowledge. If his position be that of a teacher in some secondary school, he can hardly be expected to engage in research work, but he can at least give the results of experience and observation in his particular sphere, record his methods, or state his views. Such record will be of value in proportion to the extent of his experience and the measure of his success. Even if neither of these latter be large, it may still serve a useful purpose.

The teaching of a science like chemistry may be considered under three heads,—facts, laws and theories. Every teacher of the science, I suppose, inculcates more or less of each of these, but a wide difference exists in the relative quantity of time and effort directed to each of the three. Nor is it my intention to discuss these relative quantities, but rather to accent the one of the three which seems to be taking an inferior place in some schemes of chemical study.

As facts form a basis for theories, so theories go before the enunciation of laws, and the discovery of every law is preceded by a mental theory, which, formulated, and later verified by a multitude of facts that can be predicted, becomes the embodiment of a law. If not capable of fulfilling these two conditions, verification and prediction of phenomena, it finally drops out of science as an exploded theory. What is law? And wherein is the knowledge of a law superior to that of the facts which it illustrates? *Nature's uniformity of action, under like conditions,*

is the essence of law. This habit of Nature of always doing things the same way, along lines of least resistance, admits of no exceptions. Thus a law explains a million facts. It links the hitherto unknown with the well known. It correlates natural phenomena and shows the relationship of forms of matter and of energy. People had seen millions of apples fall and watched the planets circling through space, but Newton's law of gravitation first showed that matter was bound together more closely than had been supposed. The scientific world had watched the variation of species for generations, but a revolution was produced when Darwin enunciated the law of Natural Selection and its corollary, Evolution, and proved that man was a link in a chain extending back through the darkening past to the beginning of time. Some of us can recall the amazing and revulsive effect which the first comprehension of this law produced in our minds.

The finding of *facts* in science are everyday occurences; and their discoverers, "thick as autumnal leaves," are scarcely noticed except as a *number* in the patent reports, or in the registration of new asteroids, or new compounds. But the discoverer of a law of Nature is eulogized throughout all time. Could one know all the facts of Nature, one would still be densely ignorant without the correlation of those facts which constitute laws. But could one know all her laws, one would then know Nature herself, in her varied forms, and all her secrets, and all those laws would be found but parts of one supreme law. In this aspect of the case, what study can be more sublime or more practical than that of Nature's laws? A student who experiments in science with no appreciation of its laws, learns individual facts which are soon forgotten, and which may be likened to mountain peaks sticking out above the fog. He needs to go below the mist to see how the peaks are connected. If students would get anything really valuable in chemical study, they must obtain a thorough knowledge—at least a theoretical knowledge—of the few laws that are known. F. W. Clarke says: "Scattered facts are needed preliminaries, but only with the discovery of laws and the development of broad generalizations does true science begin." Halliburton, in his recent Presidential address before the British Association, says: "After all, it is the general law which is the main object

of research; isolated facts may be interesting and are often of value, but it is not until facts are correlated and the discoverers ascertain their interrelationships that anything of epoch-making importance is given to the world." When Archimedes discovered a method of determining the purity of Hiero's crown, his joy was unbounded, not because of pleasing the king, but because he had discovered a far-reaching principle, a mode of determining the purity not only of golden crowns, but of base metals.

In the progress of science some knowledge of facts has preceded theories, as the latter have antedated the enunciation of laws. The first far-reaching theory in chemistry was that of phlogiston, founded by Becher and Stahl, in the last half of the seventeenth century. For the hundreds of years previously, isolated facts had been the chief concern of philosophers. Alchemy had made small progress. With the advent of theory, even false theory, science began and advances were made. But when phlogiston had served its century and more, and gave place to what has since been held as the true chemical theory, progress was most rapid; especially has it been so since about 1860, when the true interpretation was made of Avogadro's theory.

What *were* the ideas of philosophers before they understood that all natural phenomena was subject to law? The whole of the literature of Alchemy is filled with the notion that unseen spirits, good and bad, ruled nature, and when an Alchemist entered his secret laboratory, his supplication was poured out to these spirits to make his experiment successful. With the comprehension of law and the promulgation of theories, ghosts were dethroned, and, as a result, tremendous intellectual progress ensued.

What true science of geography was possible before Columbus and Galileo theorized? Or of astronomy before Copernicus, though it is true that facts were explained and even eclipses predicted by the Ptolemaic cycles and epicycles. It is probable that Geber in the eighth century knew a great deal about the common metals, acids and salts; but what science of chemistry was there before Lavoisier stated his theory of combustion, or Dalton put forth his atomic theory, or before Avogadro announced his hypothesis?

All three of these are nothing but theories, and may possibly never be verified or raised to the dignity of laws, but the science of chemistry rests on them, and ere the student can understand aught but bare, unexplained facts, he must have a passing acquaintance with them. Laws are founded on these theories. Think for a moment how many of the so-called laws of chemistry can be absolutely verified, can be divorced from the theories on which they rest! The laws of definite and multiple proportion can be, and with limitations, a few others. Subjectively, laws are only a step beyond theories. Take that which is called the Periodic Law. Not only is it not capable of general verification, but some able chemists declare it an exploded theory. Yet there is no other theory or law which so unites the elements into one connected chain, and few theories perhaps have done more for the science of chemistry. Again, consider Valence. Though it has never risen above the stage of theory, it subserves so useful a purpose that no student of the science can ignore it.

Theorizers, not fact-finders, are the makers of a science. Thousands before Newton saw the same phenomena that he saw. He both saw and theorized, and afterwards proved. It is often said that wrong theories hinder a science. This is hardly true. Perhaps Stas's great work would never have been done but for Prout's false theory. Better say wrong theories do not accelerate the progress of science so rapidly as right ones would. But wrong theories have always been a stimulus to experiment, a help to clear thinking, and they carry with them the weapons of their own destruction. Paracelsus had a theory that he had discovered the elixir of life and could live as long as he wished. At the age of 48 he died with a bottle of it in his hand. Almost every theory is at first erroneous, and practically none is complete. But the day of unclassed facts is past, and the difference between the scientific mind and the uneducated mind is largely that of a knowledge of classified theories on the one hand, and a knowledge of unclassed facts on the other.

The study of theories, then, is no less important than that of laws. In some respects it is more disciplinary. Suppose there are half a dozen theories to explain certain phenomena, as, for example, in geology, the cause of glacial periods, or in

chemistry, the cause of allotropy. What can be a better training of judgment than for the young student carefully to weigh each theory and then choose between them? In fact, why do we regard science study as of paramount importance for training the judgment, except as the accent is constantly put on choice of theories? Why is the study of a science often regarded as the most practical of all studies? Is it not because it prepares the student for the problems he is to meet in the world? A choice between theories must be made by the physician in diagnosing diseases, by the lawyer in his cases, by the financier in his investments, by every craftsman above the level of a routine worker. Everything in life, except pure mathematics, has an element of uncertainty in it, and is therefore subject to theory. In business life it is the probable rather than the certain that one must figure on, and this element of uncertainty requires, year by year, a keener discrimination to distinguish that which is likely to yield profit.

If these are trite sayings, and we are agreed that theory must at some time enter into the mental pabulum of the chemical student, then comes the question: At what time in the course in general chemistry should theory be taught? Some text books have put the bulk of theoretical discussion, the laws and general principles, first and by themselves. Other and later authors reverse this and place the bulk of theory, such as formulæ, valence and equations, near the end of the course, after a multitude of facts have been acquired by experimenting. This in some quarters is regarded as quite the thing to do at present. We cannot but regard it as the extreme—as much so as placing all theory first was the opposite extreme, and believe that the pendulum has swung to about its farthest limit. The final verdict of teachers is likely to settle upon the intermediate method of intermingling theory with fact, of explaining a phenomenon at the time it is observed and by the current theories. But which shall precede the other in teaching? Shall we state our chemical theorem—as in geometry—and then perform experiments to verify or illustrate it, or shall the student blindly make the experiment and then by a process of Socratic reasoning, by aid of the teacher, evolve his theory? The answer to this question has caused the most widely divergent methods. Shall we—to take a specific case—state to the

beginner who is experimenting, that he is burning carbon in oxygen, and that the product is carbon dioxid, which he himself tests by lime water, that carbon and oxygen are elements, and carbon dioxid is a compound which weighs the sum of the carbon and oxygen used? Or shall we try to have him develop those conclusions in his own mind by a series of round-about experiments, supplemented by another lot of round-about questions? The question amounts to this: Shall we state our theory at the time of experiment, or shall we evolve it afterwards? To one trained by the long, slow process of German evolutionary education—one to whom time is no consideration—the latter may seem a suitable method, even from the very outset.

It cannot be called the American method. It is not endorsed by any large percentage of chemistry teachers in colleges, technological, pharmaceutical or medical schools, academies or high schools. Some time ago I heard Prof. Wood of the Harvard Medical School in one of his matchless lectures on Arsenic, with scores of specimens of silk fabrics, papers, etc., for illustration. This was to a class in General Chemistry. Very strongly I was impressed with how much more the student got from that lecture, by that method, in an hour than he could possibly have got by induction. Those college men who advocate the inductive system exclusively, rarely make use of it themselves. Why, then, is it that a few professors of chemistry commend this method for the secondary schools? Is it because their experience has been mainly with the average school boy, or with the dullest dullards in the class, who could never possibly rank high enough to enter college? Why do they not use the method themselves with their picked students, the choicest from the secondary schools? Is it because their time is regarded as too valuable to be used in such a time-killing process? Is the high school teacher's time any less valuable? If the method is good in the one school, is it not in the other?

Text books based wholly on this principle have for the most part been failures. The method is unnatural. It is blind. It does not appeal to the average youthful mind. The man who has become steeped in chemical lore, who knows all the laws and theories, the history and development of the subject, looks at phenomena in a way different from that of the boy who

wonders why water does not run out of an inverted bottle in a pneumatic trough. The theoretical method of the one fails in case of the other.

Newth, a chemical author of wide repute, says: "In actual practice, the *purely* inductive method of instruction breaks down. There is so much that the student is required to learn that life itself is not long enough, and certainly the limited time at the disposal of the student is all too short to admit of his going through the necessarily slow process of gaining this knowledge by his own investigation." Evidences of a reaction from the extreme views are appearing. Prof. H. W. Wiley of the Agricultural Department at Washington, in a recent address, said: "I would like, therefore, to see the science training of our high schools confined to the explanation of common phenomena, and not include any expensive, time consuming and exclusive laboratory practices. This may all seem heresy," he says, "coming from a scientific man, but I believe it is good gospel, nevertheless."

Some of us have heard Prof. Shaler relate his experience with Louis Agassiz, who the first day gave him a box containing an assortment of bones, and kept him three months classifying and studying them, but never told him a thing. The method was so drastic that for every student who remained with the professor a score were driven away. My own experience in zoology in college days illustrates the point. We were taught by laboratory work with specimens, but there was no sufficient theory. All the time I wanted a classification, wanted to know where in the ordinary scheme this animal and that specimen belonged, and their relation to others of the animal kingdom. Our teacher was a professor of high rank, but my memory of aversion for the subject is tempered by a strong feeling of too much induction and too little theory. A similar experiment carried on by me at one time with large classes in chemistry for several years, only intensified the opinion that pure induction is apt to induce nothing so much as stupidity.

Is it not the psychological order that one should first know what the law is, or what the theory is, and how to state it before he attempts the proofs? Does not the opposite view savor of the topsy-turvy house of the expositions? Should one

not know where one is to bring up before one starts on a journey? But that involves stating one's theory first. Suppose, for example, in geometry the student has the figure before him and goes to work, not knowing what he is to prove or when he has finished his task. To wander indefinitely and expect to stumble upon truth is not the ideal method in research or in teaching, even though one's wanderings are directed by the best of teachers, any more than to start out to find the north pole, traversing every degree of latitude and longitude in the quest.

True, it is rather natural to grope, for the world has been groping through all the ages and not a few great discoveries have thus been made. Priestley declared that all his greatest discoveries were due to chance. But is it not unscientific to pattern after a worshipper of chance? Let a student first learn something of the accepted theories, then his own may be worth considering.

Are not the following words of President Pritchett sound doctrine? "Do not be afraid of too much theory. Never yet was good practice which was not preceded by and based upon good theory. Let your theoretical training be broad and deep. It is your only sure foundation for the best work."

Here are quotations from an advocate of the opposite view: . . . "The number of facts depending on the authoritative statement of the teacher should be kept within the narrowest limits." . . . "In no case should an experiment be done on the lecture table before it is done in the laboratory." . . . "Do not answer any questions which he can be led to answer for himself, but by a series of questions make him think out the required answer."

Though much can be said in favor of this method, I cannot believe it to be the best for beginners, especially for large classes with limited time. Is it the method practiced by religious teachers, moral instructors, or ethical advisers? Is it the method of business men? Imagine a missionary or other religious teacher who never opened his mouth to expound his doctrine. Fancy a business college that gives no instruction concerning business methods, but asks students their ideas of doing business.

Never to tell a student anything is to destroy his thirst for

information. It is killing the hen that laid the golden egg. Rather encourage his questioning propensity. The more questions the better. Answer them all so long as they are pertinent, and explain them fully. Take advantage of that attitude of mind which the student presents by his questions. The very fact that he has asked them shows that he is thinking. Crowd new facts upon his attention. Tell him every possible phase of the subject which there is time for and which he can absorb. Repeat and review it until the information becomes a part of his nature. Is not this better than stifling his questioning propensity? Giving a portion of every recitation period to answering the student's questions, I have always found one of the most helpful of exercises. One of the most suggestive teachers of science I ever studied with, said to his students at the beginning of a course: "Your success will depend wholly upon your ability to ask yourself questions." Unless we encourage our students to question us, how can we expect them to question themselves, or Nature?

Years ago, a student in my class came to me, and with tears in his eyes, said he could not understand chemistry. He had been studying it for two or three months, but with poor success. I told him if he would follow my suggestions, he would get to like the subject. He promised. He was told to take a note book, and when he began studying the text to read a sentence, and see whether it suggested any question which he could not answer. If so, he must write the question in his note book, and whenever he saw me, ask an explanation. Page after page he filled with questions. I never turned a corner without expecting to meet the young fellow with his question book, and he rarely disappointed me. Long before the close of the year, he knew more chemistry than any dozen other members of the class together. Not only that, but in after years he adopted that method of note taking in the study of finance, in which he became an authority quoted by European authors. Suppose his early questioning had been throttled? One cannot draw water from a cask which is empty, and it hardly seems best to try to make an inventor of a man until he knows something of mechanical processes. Put some positive statements into the vacant mind of the beginner before applying the suction process too vigorously. Lead the mind

by explaining what others have done. If imitation is one of the first and the best of nature's methods of teaching, why not make the most of it at the outset of a course, not discourage it? Originality will come as sure as interest is aroused, but not without it, no matter what scheme is adopted.

At what point in our chemistry teaching ought we to begin theory? Venable says: "Next to the achievement of language, the fully worked-out formula for a complex organic body represents the most wonderful accomplishment of the human mind." If the complex formula and the chemical equation, fully worked out, are the *ultima thule* of chemical theory, what knowledge does writing it involve? Fully to understand a complex equation one should know (1) The law of Conservation of Mass, (2) The laws of definite and multiple proportion, (3) The theory of Avogadro, (4) The Law of Boyle, and (5) that of Gay Lussac, on which Avogadro's theory largely rests, (6) Dalton's atomic theory, including atomic weights, (7) The molecular theory of Avogadro and Berzelius, including molecular weights, (8) Valence, and some idea of structural symbols, (9) Chemical nomenclature, (10) Berzelius's electro-positive and electro-negative division of elements. These laws need not be worked out experimentally, nor even need the *modus operandi* of verifying them be known in all cases. The laws themselves and the theories should be understood. The student of general chemistry who understands all the above items, has a good working foundation of theoretical chemistry. But should he wait till he knows all of them before writing a formula or an equation? By no means. Start him on equations as soon as he makes the initial experiments of burning wood, sulphur or iron. An equation combines the expression of a picture with a word description of an experiment. Even before that he must know symbols; first, he should know about atoms and atomic weights. Chemistry is founded on the atomic theory. Let the student know it at the outset. Have some theory in the very first lesson. The science was not till Dalton announced his atomic theory, and the student should begin at that point. Give him a clear mental picture of Dalton's conception of atoms, by using shot, marbles, or pictures. Lord Kelvin says that he cannot form a clear conception of any natural phenomenon without the aid of a model. In his

presidential address before the American Chemical Society, Professor Remsen says that without the aid of the atomic theory, he cannot co-ordinate the law of constant proportions and the law of multiple proportions. If this is true of these men, how necessary are models for beginners in science! They need nothing so much as definiteness, and the reason why theories are so difficult to teach is because they are vague. Get a clear mental picture of a theory or a law, and it becomes as any fact. Every law and every theory can be made clear by charts, pictures and mechanical devices, as the orrery has simplified astronomy and the manikin, anatomy.

Stanley Hall, in a recent address, advocated the use of models for the teaching of science to beginners. There can be no question that the best teachers employ such devices. As well might we describe experiments to our students without ever doing them, as to state laws and theories by mere words.

Yet a recent work, which pretends to tell secondary school teachers how to teach chemistry, scoffs at such mechanical methods, and leaves one to wonder whether there is really anything that can be taught in high schools by a reasonably natural method. Needless to say, its author is not a high school teacher, but a university professor.

Laws and theories should not be taught in a bunch, but intermingled with facts and experiments, as there is a demand for them; for example, one cannot go far in chemical theory without a knowledge of valence. To put off a difficult subject like valence till the last part of a course, deprives one of all the months of practice which are necessary for a working knowledge of it. Some teachers object to students using symbols and writing equations early in the course. Were they teaching French instead of chemistry, I can almost imagine them forbidding the use of French words till late in the course. If you want to know what reaction takes place, or the products of an experiment, do you not invariably try to write the equation as the simplest solution? Beginners do the same, if they know aught of chemical theory. As we used to be told, we must be able to dream in Greek before we could know

Greek, or as one must think in terms of any language before one can really be familiar with it, so we come to think in chemical symbols and equations. The earlier students acquire this ability, this habit, the better for them. By the mid-year examinations, I would have students as familiar with symbols, equations and valences, as they are with experiments. If, as Cooke says, the nomenclature and notation of chemistry are more perfect than those of any other science, is there not every reason for beginning them early ?

Time prevents my going into the subject further at present. The real test of two opposing methods should come from a comparison of results. I have not been able to ascertain that students trained by the non-communicative method, standing side by side with others, take hold of the higher branches of chemistry with one whit more cleverness, or show a keener sense of reasoning than their neighbors; whereas they are seriously handicapped by a lack of general knowledge of theories, and have consumed an amount of time greater by at least one-half.

Do I then believe in *no inductive work ?* Far from it. I was one of the earliest disciples of induction. I still believe that a class room exercise should rarely go by without it. Every proper occasion should be used to make students think independently. But it is not the only method, nor should it, in my estimation, be exclusively used, or be made the dominant factor in a chemistry course. Pure reasoning ability on a limited supply of facts is not the only equipment needed for a young man going into the world or the university. Some information is necessary.

While I have hesitated to state my views on this subject, and while I cannot expect that all teachers will give ready assent, yet variety of opinion makes for progress.

In stepping out of the office which you, fellow-members, have so generously bestowed upon me for nearly three years, I wish to express in no perfunctory or formal way my appreciation of your kindness and consideration during all that time. The little service I have been able to render has been very enjoyable

to me. My only regret on retiring is that I could not have served you better. I thank you, fellow members and members of the Executive Committee, for your co-operation, advice and support, and I bespeak for my successor, who will do better for you than I have been able, the same hearty good will.

With active committees covering every necessary field of chemical teaching, with every member working with a singleness of purpose for the good of the Association and the advancement of the profession, we ought to do much towards solving the questions of the hour.